**AIR POLLUTION AND THE SITING
OF FOSSIL FUEL POWER PLANTS**

ENVIRONMENTAL POLLUTANTS and the URBAN ECONOMY

**Argonne National Laboratory
Energy and Environmental Systems Division**

**The University of Chicago
Center for Urban Studies**

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by

**Gideon Fishelson, Gordon C. Rausser, and
Alan S. Cohen**

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AIR POLLUTION AND THE SITING OF FOSSIL FUEL POWER PLANTS

The Costs of Siting Decisions

The decision to locate a fossil fueled electrical power plant on a particular site involves trade-offs among the costs of: 1) land acquisition, 2) plant construction, operation, and maintenance, 3) power transmission, and 4) air pollution damage to humans, animals, plants and materials. The fourth of these, pollution costs, has been of great concern in recent years. But seldom, if ever, are the specific dollar trade-offs between the environmental and the other costs associated with site selection taken into account.

The sum of the costs of power generation (land, construction, operation, maintenance), power transmission, and air pollution damages (from sulfur dioxide, nitrogen oxides, and particulates) is the total social cost of a fossil fuel plant; this total cost will generally vary by site. This paper presents an analysis of the total social cost, and the trade-offs between generation/transmission and air pollution costs, for various types of fossil plants at different sites in northern Illinois. The analysis identifies the combinations of site, fossil fuel, and sulfur dioxide (SO_2) control technology that minimize total social costs.

Analysis of Social Costs

The attempt to select the best locations for different types of power plants was based upon the costs associated with generating and transmitting electricity. A complete systems optimization would also require estimates of the social costs of mining (or extracting) and transporting fuels and consuming electricity. Nevertheless, this analysis provides a useful evaluation of the social cost of electricity generation and transmission that is consistent with both the regional focus of air pollution control programs throughout the country, and the present scope of power plant siting review procedures.

Four decision variables, resulting in four design choices to be made for each power plant, were used in the analysis: site, stack height, boiler fuel, and sulfur dioxide emission control method. The site options consisted of 52 hypothetical power plant locations, spaced about 15 miles apart, in the rural and urban fringe areas of northern Illinois. Each plant was assumed to transmit its electricity to one of three fixed-location consumption centers (see Fig. 1). Stack heights were varied between 500 and 1000 ft. The fuel and sulfur dioxide control technology choices were:

- high sulfur Illinois coal (no SO_2 control),
- low sulfur Western coal (no SO_2 control),
- high sulfur Illinois coal with an SO_2 scrubber,
- high sulfur oil (no SO_2 control),
- low Btu gas obtained from an adjacent coal gasification plant,
- low sulfur oil (no SO_2 control), and
- high sulfur oil with an SO_2 scrubber.

Fig. 1. Study Area.

Electrostatic precipitators for controlling particulate emissions with operating efficiencies of 99% for Illinois coal, 98% for Western coal, and 94% for oil were assumed to be used. Also, power plants were presumed to be of a given unit size; thus, potential economies of scale of the unit size or of more than one unit within a plant were not considered. The assumed values for various plant and fuel parameters are listed in Table 1.

Air pollution damages from sulfur dioxide, suspended particulate matter, and nitrogen oxides were calculated using population forecasts for 1980 and damage factors of \$1.25, \$2.50 and \$1.00/ $\mu\text{g}/\text{m}^3$ /person/year, respectively. The damage factors for SO_2 and particulates are about the mid-range figures reported by Cohen et al.,^{*} adjusted for the 1974 price level; the nitrogen oxides factor was calculated using the proportionality factor to sulfur dioxide as reported by Babcock and Nagda.^{**} These damage factors reflect human mortality and morbidity, and material corrosion and soiling effects of these pollutants. The magnitude of vegetation and animal damages in the study area was insignificant, relative to the human and material damages; therefore, these damages were not explicitly considered.

^{*}Cohen, A. S., G. Fishelson, and J. L. Gardner, *Residential Fuel Policy and the Environment*, Cambridge, Mass., Ballinger Publishing Co., 1974.

^{**}Babcock, L. R. and N. L. Nagda, *Cost Effectiveness of Emission Control*, Journal of the Air Pollution Control Assn., 23(3): 173-79, 1974.

The use of constant damage factors precludes the need to consider time-varying pollution concentrations. Therefore, these air pollution damage factors applied to annual average pollution estimates are sufficient for predicting total annual damages. The use of non-linear damage functions could alter the analysis' results.

The costs of air pollution were calculated by multiplying an estimated pollutant level by the population exposed to that level by the appropriate damage factor. Estimates of the SO₂ and particulate levels were obtained using the Air Quality Display Model (AQDM). Nitrogen oxides were assumed to disperse like sulfur dioxide. Meteorological data from Chicago, Peoria, and Rockford, Illinois, were used to obtain spatial variations in meteorological conditions for the different power plant sites.

Because hypothetical rather than actual sites were analyzed, the land, labor, construction, fuel, operating, and maintenance costs for each type of fossil fuel plant were assumed to be the same for all locations. Therefore, only transmission-related costs and air pollution damages were location dependent. The costs of transmission line investment, maintenance, and operation; electricity losses from the lines; and transmission line reliability were assumed to be proportional to the distance between the plant site and one of the three consumption centers. The analysis identifies the maximum regulated distance from population centers that can be economically justified for reduction of air pollution damages. (If the costs assumed constant do vary systematically with distance this maximum distance could be revised accordingly.) Beyond this maximum distance, the additional transmission costs would exceed any savings gained from reduced pollution damages.

TABLE 1. Power Plant and Fuel Parameters

	Illinois Coal	Western Coal	Illinois Coal and Scrubber	High Sulfur Oil	Coal Gasification	Low Sulfur Oil	High Sulfur Oil and Scrubber
Number of Generating Units	3	3	3	5	3	5	5
Total Capacity (MW)	2400	2400	2400	2500	2400	2500	2500
Annual Utilization Rate/Unit (%)	65	65	65	65	65	65	65
Heat Rate (Btu/kWh)	8900	9350	9800	8830	10,700	8830	9700
Fuel Price* (\$/10 ⁶ Btu)	0.60	0.90	0.60	1.25	0.60**	1.50	1.25

*Prices reflect the post embargo (beginning, 1974) fuel market in northern Illinois.

**Price of Illinois coal fuel input.

Results of the Analysis

The estimated air pollution damages that would be caused by each of the seven alternative power plant types located at 15 of the 52 sites considered in the analysis are shown in Table 2. Among the 15 representative locations selected for inclusion in this table are those with the most significant – i.e., maximum, minimum, optimum – pollution costs and total social costs. The maximum air pollution cost (Illinois coal at site 11), which is less than 2.0 mills/kWh, is about 15% of the total social cost of generating electricity with Illinois coal at site 11. Comparison of Table 2 with Figure 1 shows that damages fall quite rapidly as the plant locations shift westward into areas having relatively low population densities. For example, for Illinois coal the damage is 1.91 mills/kWh at site 11, but only 0.19 mills/kWh at site 15.

The figures in Table 2 were combined with estimates of the generation/transmission and stack construction costs to identify the optimal location (i.e., lowest sum of generation/transmission, stack construction, and pollution costs) for supplying electricity to each of the consumption centers A, B, and C. These

TABLE 2. Environmental Costs of Fossil Fueled Power Plants* (mills/kWh)

Location	Illinois Coal	Western Coal	Illinois Coal and Scrubber	High Sulfur Oil	Coal Gasification	Low Sulfur Oil	High Sulfur Oil and Scrubber
1	0.96	0.54	0.62	0.34	0.29	0.16	0.21
4	0.43	0.24	0.28	0.15	0.13	0.07	0.09
6	1.39	0.79	0.89	0.49	0.43	0.23	0.30
11	1.91	1.08	1.23	0.67	0.59	0.32	0.41
15	0.19	0.11	0.12	0.07	0.06	0.03	0.04
16	1.82	1.03	1.17	0.64	0.56	0.31	0.39
20	0.16	0.09	0.11	0.06	0.05	0.03	0.04
21	1.65	0.93	1.45	0.58	0.50	0.28	0.35
22	1.59	0.90	1.02	0.56	0.49	0.27	0.34
31	0.17	0.10	0.11	0.06	0.05	0.03	0.04
35	0.27	0.16	0.18	0.10	0.08	0.05	0.06
40	0.11	0.06	0.07	0.04	0.03	0.02	0.02
41	0.16	0.09	0.10	0.06	0.05	0.03	0.03
44	0.11	0.06	0.07	0.04	0.03	0.02	0.02
52	0.10	0.05	0.06	0.03	0.03	0.02	0.02

*For 1980 population and stack height of 500 feet.

locations were found to be sites 15, 31, and 35, which are 56.7, 45.2, and 44.6 miles from their respective consumption centers (see Fig. 1). The total social costs were estimated to be 14.79, 14.64, and 14.73 mills/kWh, respectively. This finding was based on a 65% annual utilization rate assumed for all fossil power plants. If the utilization rate is allowed to range between 55 and 75%, the social costs of these three optimal locations vary from 13.44 to 16.44 mills/kWh – the higher the utilization rate, the lower the social costs. Changing the utilization rate did not alter the optimal locations, stack heights, fuel, or SO₂ control choices.

Social costs also vary with changes in the four decision variables – site, stack height, fuel, SO₂ control method – used in the analysis. When Illinois coal (no scrubber) and a 500 ft stack are used, the maximum deviations of total social costs between all locations are 1.30, 1.48 and 1.59 mills/kWh, respectively, for consumption centers A, B, and C – a range that represents less than 11% of the total social cost of supplying electricity with Illinois coal. If, however, stack heights are allowed to vary, the difference in social costs among locations is even smaller: a maximum of 0.76 mills/kWh, or less than 6% of the social cost. The difference in social costs is reduced when stack heights are varied because the optimal stack height for Illinois coal plants increases as the sites move closer to population centers. The optimal stack height at site 11, for example, is 1,000 ft.

The variability in social costs for different fuel/sulfur dioxide control choices is significantly greater than for location and stack height changes. Table 3 shows the estimated difference in total social costs of the various plant types at those locations where the use of Illinois coal is the least attractive (most expensive), i.e., those sites closest to the Chicago metropolitan area. (A stack height of 500 ft was assumed for this table, which maximizes Illinois coal costs and minimizes the difference between

TABLE 3. Differential Social Costs of Various Fossil Fueled Power Plants (mills/kWh)

Location	Illinois Coal	Western Coal	Illinois Coal and Scrubber	High Sulfur Oil	Coal Gasification	Low Sulfur Oil	High Sulfur Oil and Scrubber
	Total Social Cost	Differential* Social Cost					
1	15.18	3.08(20%)	3.76(25%)	3.98(26%)	4.73(31%)	6.00(40%)	7.75(51%)
6	15.44	2.90(19%)	3.60(23%)	3.70(24%)	4.44(29%)	5.64(37%)	7.41(48%)
11	16.01	2.67(18%)	3.42(21%)	3.36(21%)	4.08(25%)	5.21(33%)	7.00(44%)
16	15.88	2.71(17%)	3.45(22%)	3.42(22%)	4.14(26%)	5.29(33%)	7.07(45%)
21	15.70	2.78(18%)	3.50(22%)	3.53(22%)	4.25(27%)	5.43(35%)	7.20(46%)
27	15.18	3.60(24%)	4.70(31%)	3.74(25%)	4.70(31%)	3.94(26%)	5.96(39%)
33	15.11	3.16(21%)	3.82(25%)	4.09(27%)	4.86(32%)	6.15(41%)	7.89(52%)

*The difference is the social cost of using the indicated technology less the social cost of using Illinois coal.

Illinois coal and competing fuel/SO₂ control options.) Table 3 indicates that the use of Illinois coal, without an SO₂ scrubber, results in the lowest total social cost at all locations. This is also true for the other 45 sites considered in the analysis but not included in the table. The use of Western coal, the next most attractive alternative, would result in a minimum increase in social costs of 17%.

Sensitivity of the Results

A number of parametric analyses were performed to test the sensitivity of the conclusion that the use of Illinois coal minimizes total social costs for all the locations considered in the study. To illustrate the types of parameter changes required to alter this conclusion, consider a plant with a 500 ft stack located at site 11. The air pollution damage factors would have to be more than four times as great as those used in the analysis before Illinois coal burned without SO₂ controls would not minimize social costs. In that case, Western coal would become the best option.

Without increasing the damage factors, the cost differences in mills/kWh between Illinois coal and Western coal, high sulfur oil, and low sulfur oil would have to be reduced by more than 88%, 58% and 65%, respectively, before the use of these fuels would result in total social costs less than those of Illinois coal.

The capital costs of a coal gasification plant would have to be reduced by more than 76% (to less than \$40/kWh), and its operating and maintenance costs reduced by more than 40% before coal gasification would become superior to Illinois coal.* The parametric changes required to make the scrubber option, regardless of fuel, economically justified are so extreme that it is unlikely that this option could ever be optimal in the Chicago area.

The above analyses indicate that the conclusion that Illinois coal, with no SO₂ controls, is the best boiler fuel to be used in rural and urban fringe power plants located in northern Illinois is robust. The result is further strengthened when one considers the fact that the above analyses are for a plant located relatively close to the Chicago metropolitan area with a relatively short stack. The superiority of Illinois coal increases for plants further from the populated area and/or for plants with taller stacks.

Policy Implications

The results of this analysis indicate that appropriate horizontal and vertical displacement of power plant emissions can minimize the local social costs of power generation and transmission in the northern Illinois area (assuming the particulate controls described on page 6). Furthermore, the environmental damage differential between alternative power plant sites in rural areas is a small percentage (less than 6%) of the total social costs of generating electricity. Forcing power plants to locate more than 60 miles from the boundaries of the Chicago metropolitan area in order to reduce air pollution damages also would most likely not be an economically desirable air pollution/land use policy, since at that point, the added transmission costs would exceed any pollution damage savings.

*Other combinations of changes in capital, operating and maintenance, and fuel penalty parameters could make the coal gasification option superior to the Illinois coal option, but a reduction in capital costs alone would be insufficient.

Appropriate horizontal and vertical displacement of power plant emissions
can minimize the local social costs of power generation.

A few qualifications to the results should be emphasized. The advantages and limitations of spatial adaptation as a means of reducing air pollution damages cannot be stated precisely for regions other than the one studied. However, the Illinois results do indicate that there is a considerable advantage to this type of land use control and it should be given more consideration. Because only rural and urban fringe plant locations were analyzed, the conclusions should not be generalized to include power plants located within highly populated areas. Additionally, the analysis reflects only *local* air pollution damages. Although the potential damages from long distance transport of pollutants might affect the selection of the best technology, they would probably have little effect on the selection of the best locations within the study area.

Aesthetic damages from transmission lines and animal and vegetation damages were not included in the calculations. If included, they would tend to shift the optimal power plant locations closer to the heavily populated area, because the total cost of transmission (including aesthetic damages) would increase slightly and the difference in the air pollution damages as sites moved further from populated areas would decrease slightly. However, the optimal fuel and SO_2 technology choices probably would not be affected, since the health and material damages that were considered are significantly greater than the omitted ones, and at least a four-fold increase in the damage factors is required before the decision choices are altered.

**For further information on the
study described in this report,
please contact:**

**Dr. A. S. Cohen
Argonne National Laboratory
Energy and Environmental Systems Division
9700 South Cass Avenue
Argonne, Illinois 60439**

or

**Prof. G. S. Tolley
The University of Chicago
Department of Economics
1126 East 59th Street
Chicago, Illinois 60637**